Effects of Ag Buffer and Pt Intermediate Layers on Magnetic Properties of Epitaxial Co/Pt Multilayers

D. H. Wei, S. C. Chou, T. S. Chin, C. C. Yu, Y. D. Yao, and Y. Liou

***Abstract*—Co/Pt multilayers were prepared on silicon substrates with a Ag buffer of different thickness and Pt intermediate layers by using the molecular-beam epitaxial technique. The as-deposited films (at 160 °C) were then post-annealed for 30 min in a vacuum at a temperature ($T_{\rm an}$) ranging from 260 °C to 500 °C. The formation of CoPt $L1_0$-ordered structure were observed for all the samples grown at 160 °C. The out-of-plane coercivity ($Hc_{\perp}$) and saturation magnetization ($Ms_{\perp}$) of all Co/Pt multilayer films decreased monotonically as elevating annealing temperature, owing to the heavy diffusion of Si into Co/Pt films at higher temperatures. When $T_{\rm an}$ reaches 500 °C, the formation of PtSi phase destroys the magnetic properties.**

***Index Terms*—Buffer layer, Co/Pt alloy, multilayer deposition, ordering temperature, Si interdiffusion.**

I. Introduction

CoPt thin films are widely investigated due to their high potential for magnetic recording media at ultrahigh densities and with a large magnetocrystalline anisotropy constant ($Ku \sim 5 \times 10^7$ erg/cm^3) [1]. This high Ku value could maintain thermal stability to resist thermal fluctuation and demagnetization fields. To achieve ultrahigh recording densities, the grain sizes must be reduced to about 10 nm. The easy axis either in-plane or perpendicular directions can be manipulated by choosing the buffer layer. The (111) plane is the close-packed plane of CoPt phase, so the CoPt thin films deposited even directly onto a single-crystal substrate without suitable buffer layer tends to have (111) texture. The CoPt film has to be annealed at a temperature usually higher than 500 °C in order to obtain CuAu [I] type $L1_0$ structure [2], [3]. Recently, many works were reported on reducing the ordering temperature by multilayer-growth [4], [5], ion irradiation [6], [7], or addition the third elements [8], [9].

In previous papers [10], [11], we successfully manipulated epitaxial Ag(100) buffer layer on Si(100) substrate and then grew Fe and Co films with proper textures. In this paper,the Ag buffer layer was not only used to induce epitaxial growth of the Co/Pt multilayers on Si(100) substrates but also to reduce the interdiffusion of Si into multilayers. The lattice misfit of CoPt with Pt (4.59%) is smaller than that with Ag (8.55%), therefore, a Pt intermediate layer was deposited between the CoPt and Ag buffer to reduce the lattice misfit. In order to understand the effects of using Ag buffer and Pt intermediate layers, the thickness of Ag and Pt layers were varied to investigate the changes in structural and magnetic properties. Post annealing at different temperatures was done to study the effects on the Co/Pt multilayer films.

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TABLE I
Co/Pt Multilayers With Different Film Structures

Sample	Film structures
A	Si/Ag 5 nm/Pt 5 nm/[Co 0.5 nm/Pt 1 nm]$_{17}$
B	Si/Ag 10 nm/Pt 5 nm/[Co 0.5 nm/Pt 1 nm]$_{17}$
C	Si/Ag 20 nm/Pt 5 nm/[Co 0.5 nm/Pt 1 nm]$_{17}$
D	Si/Ag 10 nm/Pt 10nm/[Co 0.5 nm/Pt 1 nm]$_{17}$

II. Experimental Procedures

In this paper, $[\mathrm{Co}(0.5\ \mathrm{nm})]/\mathrm{Pt}(1\ \mathrm{nm})]_{17}$ multilayers fixed at a 25.5-nm thickness were grown on Si(001) substrate with a Ag buffer of thickness 5, 10, and 20 nm, respectively, and subsequently a Pt intermediate layer of thickness 5 and 10 nm, respectively; by using the molecular-beam epitaxial (MBE) technique. Table I shows the film structures for the four series samples. The Ag buffer layer was deposited at 400 °C by a Knudsen cell, and the Pt intermediate layer was deposited at 300 °C. Co/Pt multilayers were then deposited onto Pt intermediate layers at 160 °C via e-beam evaporation. The deposition rates of Ag, Co, and Pt were controlled at 0.05 Å/s. After deposition, the samples were annealed at a temperature ($T_{\rm an}$) range from 260 °C to 500 °C for 30 min in a vacuum of 5×10^{-9} torr. The crystal structure was studied by *in situ* reflection high-energy electron diffraction (RHEED) and *ex situ* X-ray diffraction (XRD) with Cu K_α radiation. The cross-sectional microstructure was observed by transmission electron microscopy (TEM). The magnetic properties were measured at room temperature by using a vibrating sample magnetometer (VSM) with a field up to 1.2 T.

III. Results and Discussion

XRD patterns for Si/Ag 10 nm/Pt 5 nm/[Co 0.5 nm/Pt 1 nm]$_{17}$ multilayers (B sample) grown at 160 °C, and then annealed at a temperature ($T_{\rm an}$) 260 °C, 330 °C, 400 °C, and 500 °C, respectively, are shown in Fig. 1(a)–(e). The unlabeled sharp peaks are due to the Si substrate. The angles of the 200 peaks of Ag and Pt layers shift to high and low angles, respectively, by increasing the annealing temperature. It also indicates that Ag and Pt layers tend to form AgPt alloy at higher $T_{\rm an}$. From diffraction peaks of Ag, Pt, and CoPt, it indicates the growth of (001) texture.

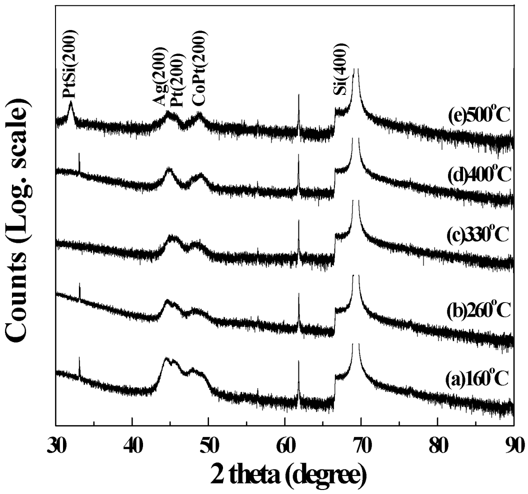

Fig. 1. XRD patterns of the B films grown at (a) 160 °C and then annealed for 30 min at (b) 260 °C, (c) 330 °C, (d) 400 °C, and (e) 500 °C, respectively.

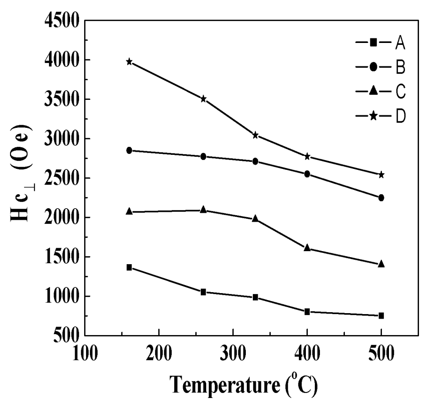

Fig. 2. Out-of-plane coercivity as a function of annealing temperature of type A, B, C, and D films.

The formation of CoPt $L1_0$ ordered structure is observed for all the samples. The CoPt (200) peak is getting sharper as increasing T_{an}. This indicates that the grain size is increased with increasing T_{an}. Since the Co layers were quite thin (0.5 nm), it is most possible that Co atoms were fully mixed with Pt atoms even at the low growth temperature (160 °C). When the T_{an} is increased to 500 °C, PtSi compound phase is observed as shown in Fig. 1(e).

Fig. 2 shows the out-of-plane coercivity of the four series of multilayer films with different thickness of Ag buffer and Pt intermediate layers and after different post annealing. It indicates a good perpendicular magnetic anisotropy at the as-deposited state. The CoPt alloy should formed at the interface between Co and Pt layers (see Fig. 1). This growth method of multilayers also successfully reduces the ordering temperature of CoPt alloy, that otherwise requires > 500 °C.

At as-deposited state, the coercivity of the films with Ag buffer 5 nm (sample A) is about 1366 Oe. It increases to about 2850 Oe with Ag 10 nm (sample B), and then decreases to 2068 Oe with Ag 20 nm (sample C). The coercivity enhancement is due to the good texture growth for Sample B films. However, when the Ag thickness reaches 20 nm, island structure formed, as evidenced in Fig. 3, to introduce large inhomogeneities that may serve as the nucleation sites for the

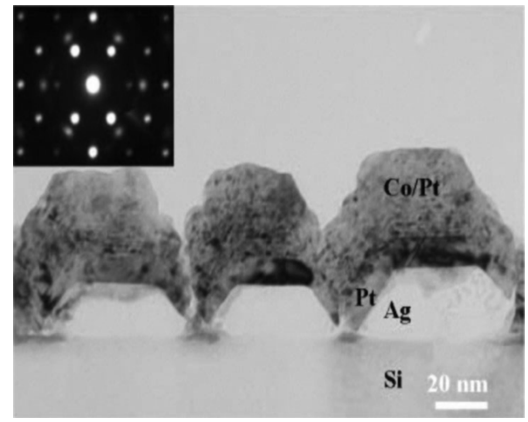

Fig. 3. Cross-sectional TEM image of a C film and inset is the corresponding selected-area election diffraction pattern.

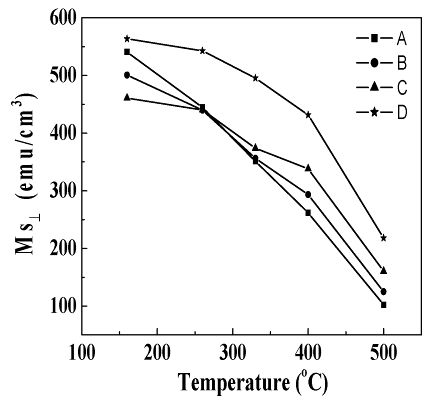

Fig. 4. Variation of the saturation magnetization (Ms) with annealing temperature of type A, B, C, and D films.

reversal domains. This would deteriorate the coercivity of the CoPt films. Fig. 3 shows the cross-sectional TEM micrograph of as-deposited type C films, and one can clearly see that the Ag buffer forms island structure. Pt intermediate layer and Co/Pt multilayers grew intimately on the underlying Ag island structure. The inset is the corresponding selected-area election diffraction pattern. It also indicates that all films grow epitaxially on the Si(100) substrate.

From the results of coercivity values, we chose B film to further study the effects of Pt intermediate layer. The type D films were prepared with the thickness of Pt varied to 10 nm. The coercivity of the films increases with increasing Pt intermediate layer thickness. However, the coercivity after post annealing of Co/Pt multilayers decreases monotonically as elevating T_{an} as indicated in Fig. 2. The results suggest that the fct-CoPt phase earlier formed at 160 °C was deteriorated by the Si interdiffusion into the multilayers, as increasing annealing temperature leading to decreased coercivity.

Fig. 4 shows the relationship between the perpendicular saturation magnetization (Ms) and the T_{an} of four series CoPt films. The Ms value of Co/Pt multilayers is decreased as T_{an} is increased. The reason is due to heavy interaction between CoPt films with Si substrate with increasing T_{an}. From the Ms values of as-deposited A, B, and C samples, it is evident that by increasing thickness of Ag buffer, the Ms value is decreased. It can be understood that Ag is a nonmagnetic element, and

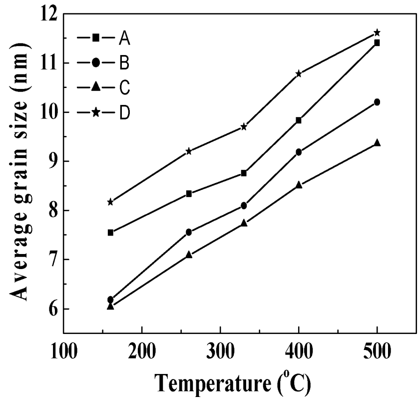

Fig. 5. Average grain size of type A, B, C, and D films as a function of annealing temperature.

it plays the simple role of diluting the magnetization of Co/Pt films. Compared with sample B, the magnetization of sample D is larger than that of B. This is owing to the effect of Co-Pt interface on the magnetization [12]. The magnetization of Co/Pt films is increased due to the polarization of the Pt atoms.

Fig. 5 shows the average grain size of Co/Pt films as a function of annealing temperature. Grain sizes of these films are calculated from the Scherrer's formula by using the measured width of CoPt diffraction peaks [13]. The grain size increases with increasing annealing temperature. The grain size decreases by increasing thickness of Ag buffer but increases with increasing thickness of Pt intermediate layer.

IV. Conclusion

High perpendicular magnetic anisotropy Co/Pt multilayers grown by MBE at a low deposited temperature (160 °C) were successfully fabricated by adopting a Ag buffer and Pt intermediate layers. By adjusting the thickness of Ag buffer and Pt intermediate layers, the coercivity of CoPt films can be controlled. At the thickness of 10 nm for both Ag buffer and Pt intermediate layers (Sample D), the out-of-plane coercivity reaches the maximum value of around 4000 Oe. The coercivity of all Co/Pt multilayers decreased monotonically as increasing the post-annealing temperature. The Ms value of the film decreased with increasing annealing temperature and Ag buffer thickness. The average grain size of CoPt particles increased with increasing annealing temperature but decreased with increasing Ag buffer thickness.

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